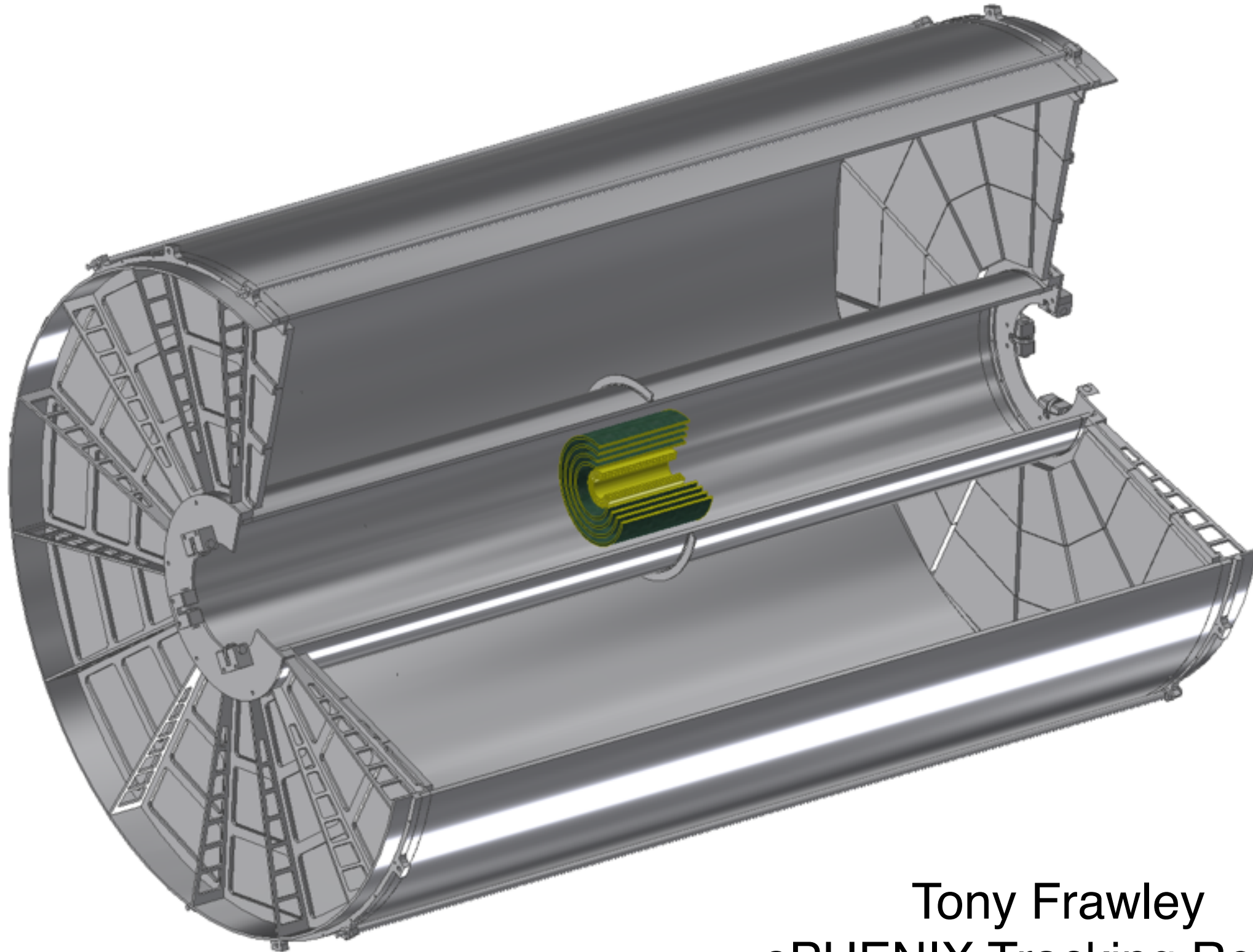


Tracker Simulations



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Goals

Physics program driven goals of tracking simulations:

Momentum resolution

- Upsilon program requires σ_{mass} for Upsilon of < 100 MeV
 - Determined by decay electron momentum resolution at 5 - 10 GeV/c
- Jet physics program requires $\sigma_{p_T} \sim$ a few percent at ~ 40 GeV/c

DCA resolution

- Heavy flavor tagged jets require $\sigma_{\text{DCA}} < 100$ μm (smaller the better!)

Single track efficiency - important for multi-track measurements

- Heavy flavor tagged jets require multi-track measurements
- Upsilon require di-electron measurements

Pattern recognition

- Fake tracks in Au+Au \longrightarrow background noise in jet measurements

Tracking simulations

All results shown here use a model where each tracking detector consists of uniform cylindrical tracking layers of sensitive material and uniform cylindrical layers representing inactive support material.

Silicon trackers:

- Layer of sensitive Si divided into pixels (MAPS) or strips (INTT)
- Layer of Cu to make up the total average thickness

TPC

- Layer of inactive material for inner field cage
- layer of inactive gas from 20-30 cm radius
- 60 layers of active gas divided into “voxels” of 1.5 mm x 1.7 mm
- layer of inactive material for outer field cage

Tracking active layers

Layer	Type	Radius (cm)	active thickness	total thickness (X_0)	cell pitch	cell length (in Z)
0	MAPS	2.3	50 μm	0.3%	20 μm	20 μm
1	MAPS	3.2	50 μm	0.3%	20 μm	20 μm
2	MAPS	3.9	50 μm	0.3%	20 μm	20 μm
3	Si strip	6.0	120 μm	1%	80 μm	1.2 cm
4	Si strip	8.0	120 μm	1%	80 μm	1.2 cm
5	Si strip	10.0	120 μm	1%	80 μm	1.2 cm
6	Si strip	12.0	120 μm	1%	80 μm	1.2 cm

7-67*+ TPC gas 30-80 cm 50/60 cm $1\%+0.2\%$
+1% 1.5 mm 1.7 mm

*TPC layer counts of 30 and 48 tested, no performance degradation
+TPC gas volume also includes dead area from 20-30 cm radius

MAPS pixel simulations

MAPS pixels ($28\text{ }\mu\text{m} \times 28\text{ }\mu\text{m}$) not isolated from each other

- Electrons will be shared by multiple pixels
- This improves the position resolution

Charge sharing not yet included in the simulation

- Most hits in sims are single pixel
- Estimated effective position resolution is $20\text{ }\mu\text{m} / \sqrt{12}$
- So the pixel size is set to $20\text{ }\mu\text{m}$ in simulation

Active depth of pixels is $19\text{ }\mu\text{m}$

- For historical reasons, we use $50\text{ }\mu\text{m}$ in simulation
- But we adjust thresholds to match performance expectations from ALICE experts

TPC simulations

Electron drift and diffusion in gas

Uses measured parameters for T2K gas: Ar (95%) CF₄ (3%) isobutane (2%)

We plan to swap 95% Ar to 95% Ne

- Less than 10% change in diffusion and other properties

Readout plane

Longitudinal diffusion (+ tilt) smears drift distance, preamp smears time - add in quadrature

Want charge on 3 readout pads - pad size set by transverse diffusion

Cluster 3 readout pads and 5 time bins when track crosses one “layer”

Space charge distortion:

Size of effect from simulations using formulae from Rossiger thesis (ALICE calculations)

Ratios of maximum distortion to corrected precision from:

- Actual performance in STAR, simulations in ALICE

STAR uses analytic calculation scaled by luminosity, ALICE claims better ratio

Used STAR ratio as our default - applied as offset **and** as sigma

Also studied making factor worse, got little degradation

We get small space charge distortion using two tricks:

- Operate in zone favoring lowest ion back flow (trade off against dE/dx performance)
- Put entrance of field cage at 20 cm, moves max distortion point outside tracking volume
 - 3 cm distortion at 20 cm drops to **3 mm at 30 cm** (20 cm at inner field cage for ALICE)

Intermediate tracker will allow us to check distortion corrections (not taken credit for here)

Tracking software

Start with G4 hits with energy loss

- Digitize cell energy, apply threshold
- Cluster cell hits, apply threshold, estimate position uncertainties
- Clusters are input to tracker

Track:

- Hough transform to find tracks in helix parameter space
- Kalman filter to fit tracks
- Ghost rejection to reject duplicate tracks with poorer χ^2

Evaluation module to gather and crosslink diagnostic information

- Truth hits
 - With link to truth track
- Truth tracks
- Reconstructed track details
 - With link to dominant truth track
- Reconstructed clusters
 - With links to associated truth hits, truth track, reconstructed track

Performance simulations with Hijing + embedded pions

Central Hijing events (0-4 fm) +100 embedded pions each.

Embedded pions

- $p_T = 0.5 - 50$ GeV/c in steps of 0.5 GeV/c.
- p_T and DCA (bend plane) resolution plots
 - embedded pion tracks only
- Single track efficiency plots
 - embedded pions only, using a 4σ cut on reconstructed p_T .

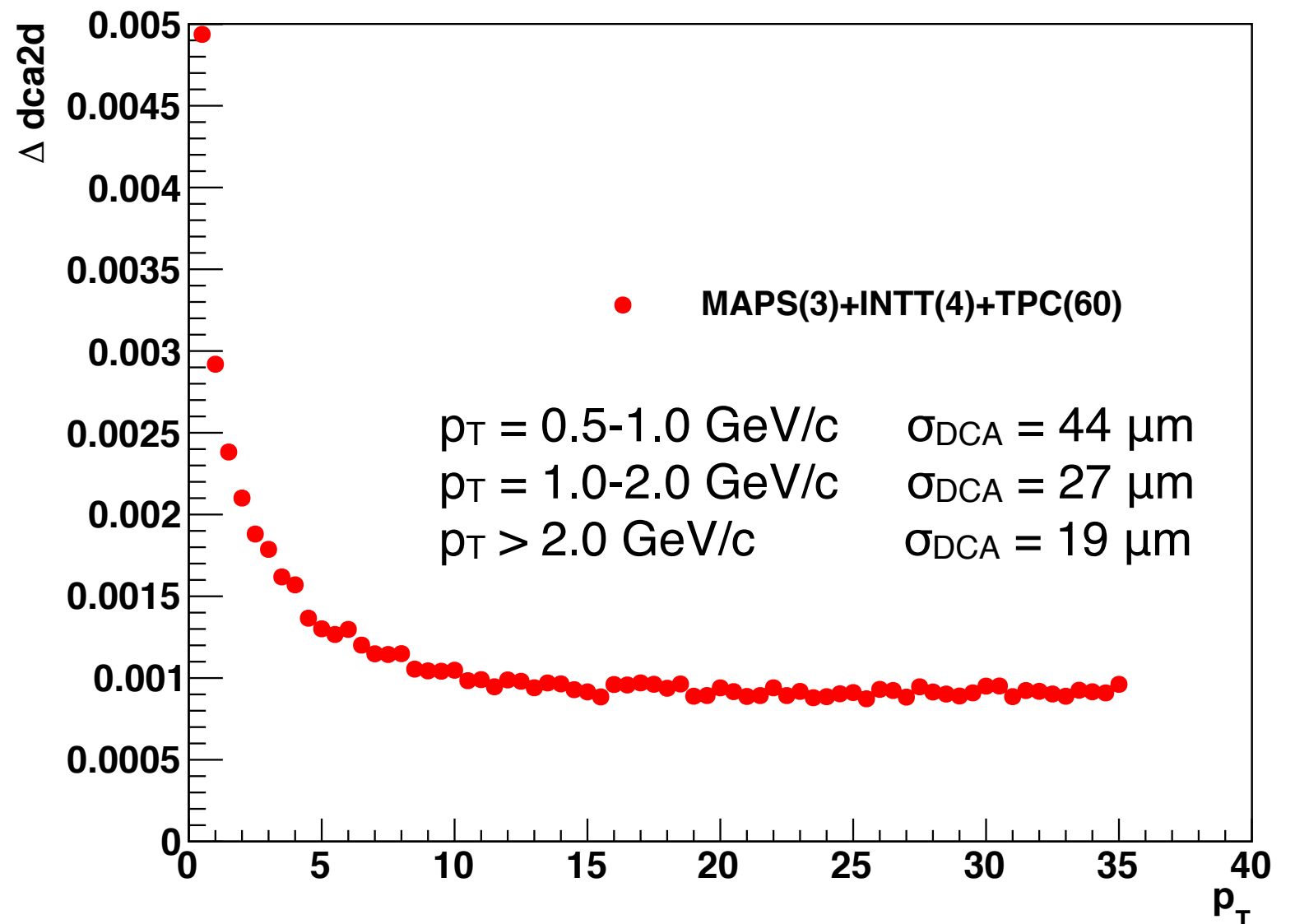
Hijing tracks

- DCA distributions and track purity plots (Hijing tracks only).
- Track purity plots (Hijing tracks only)

DCA resolution

embedded pions only
central Hijing
+ 100 pions/event

quality < 1.5
dca2d < 1 mm
dcaZ < 1 mm

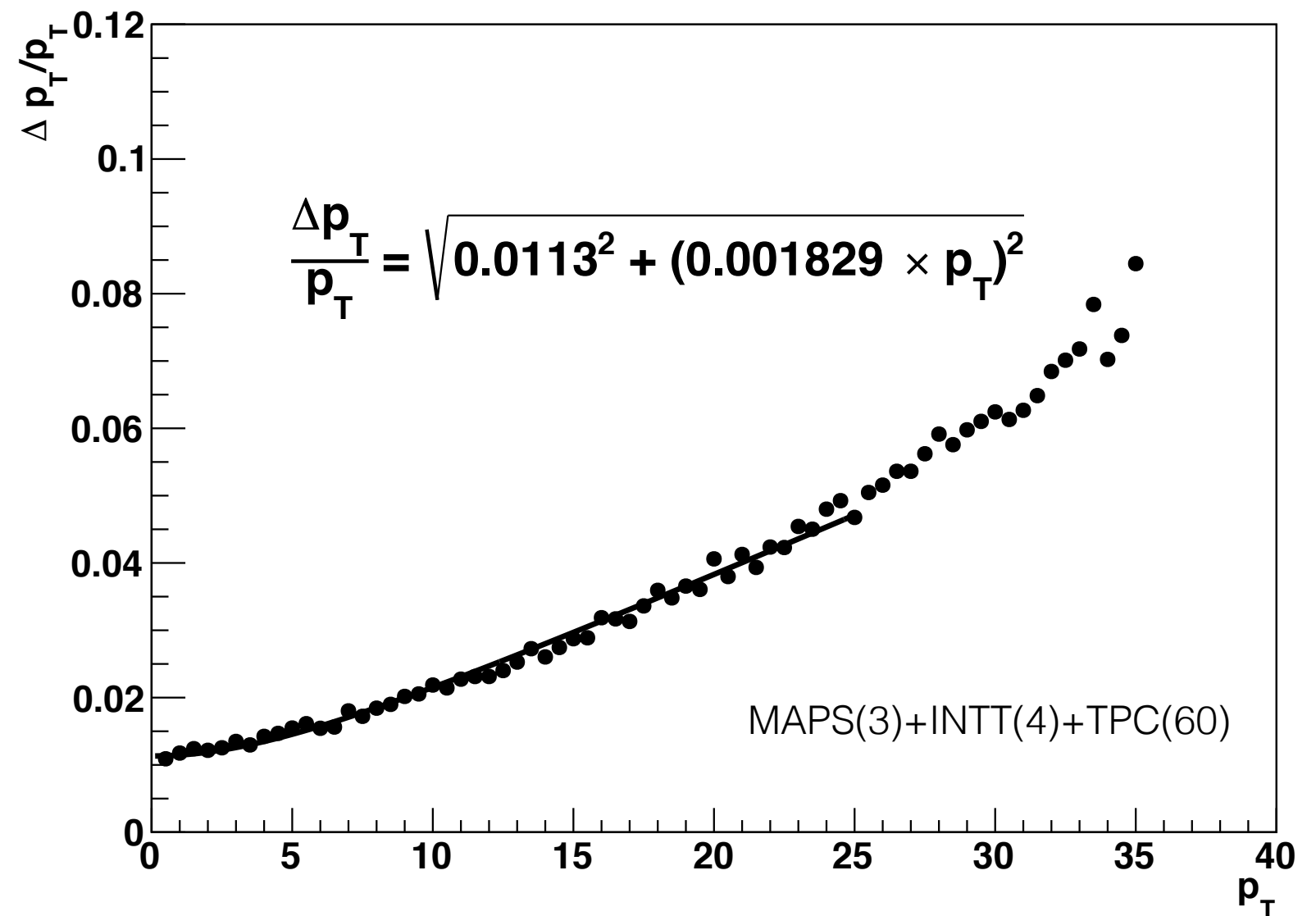


Easily exceeds sPHENIX
specification of < 100 μm

Momentum resolution

embedded pions only
central Hijing
+ 100 pions/event

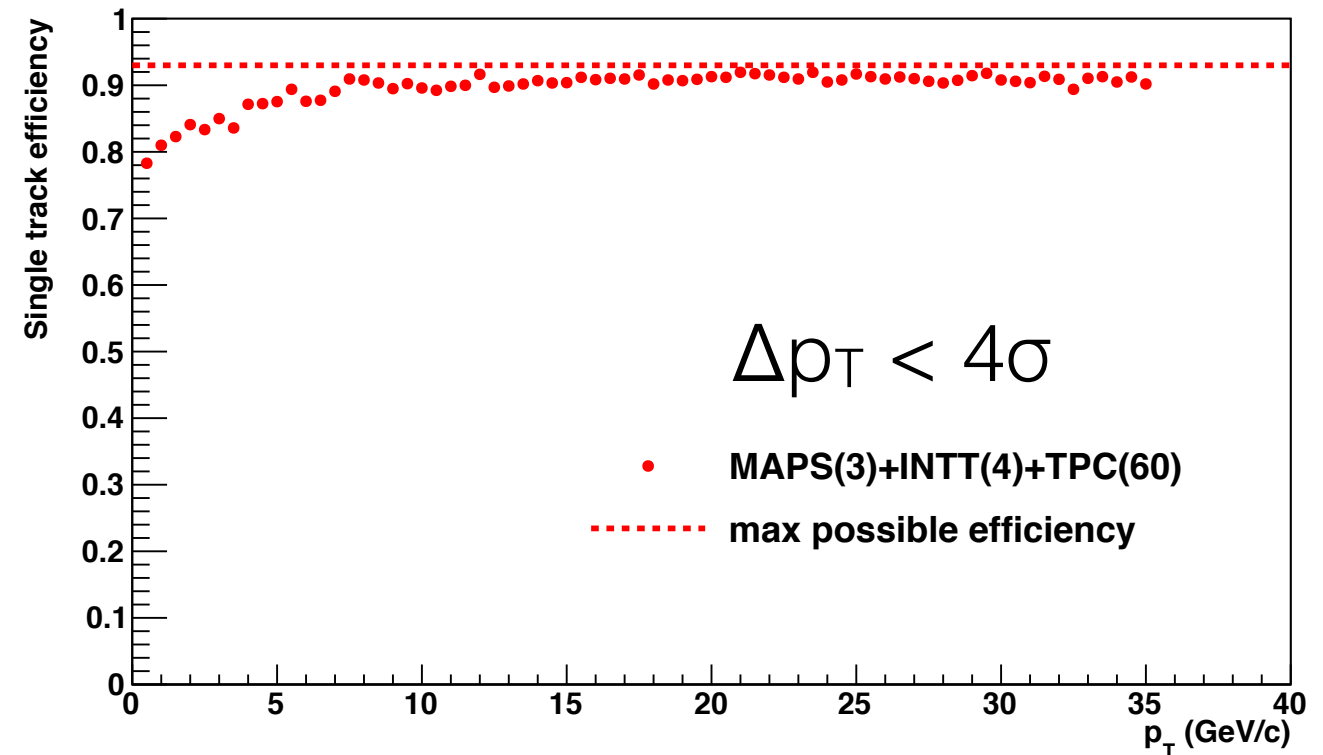
quality < 1.5
dca2d < 1 mm
dcaZ < 1 mm



Single track efficiency

embedded pions only
central Hijing
+ 100 pions/event

quality < 1.5
dca2d < 1 mm
dcaZ < 1 mm



Algorithm:

Loop over **truth** tracks

- Find matching reconstructed track
- Check if reconstructed $p_T < 4\sigma$ from truth

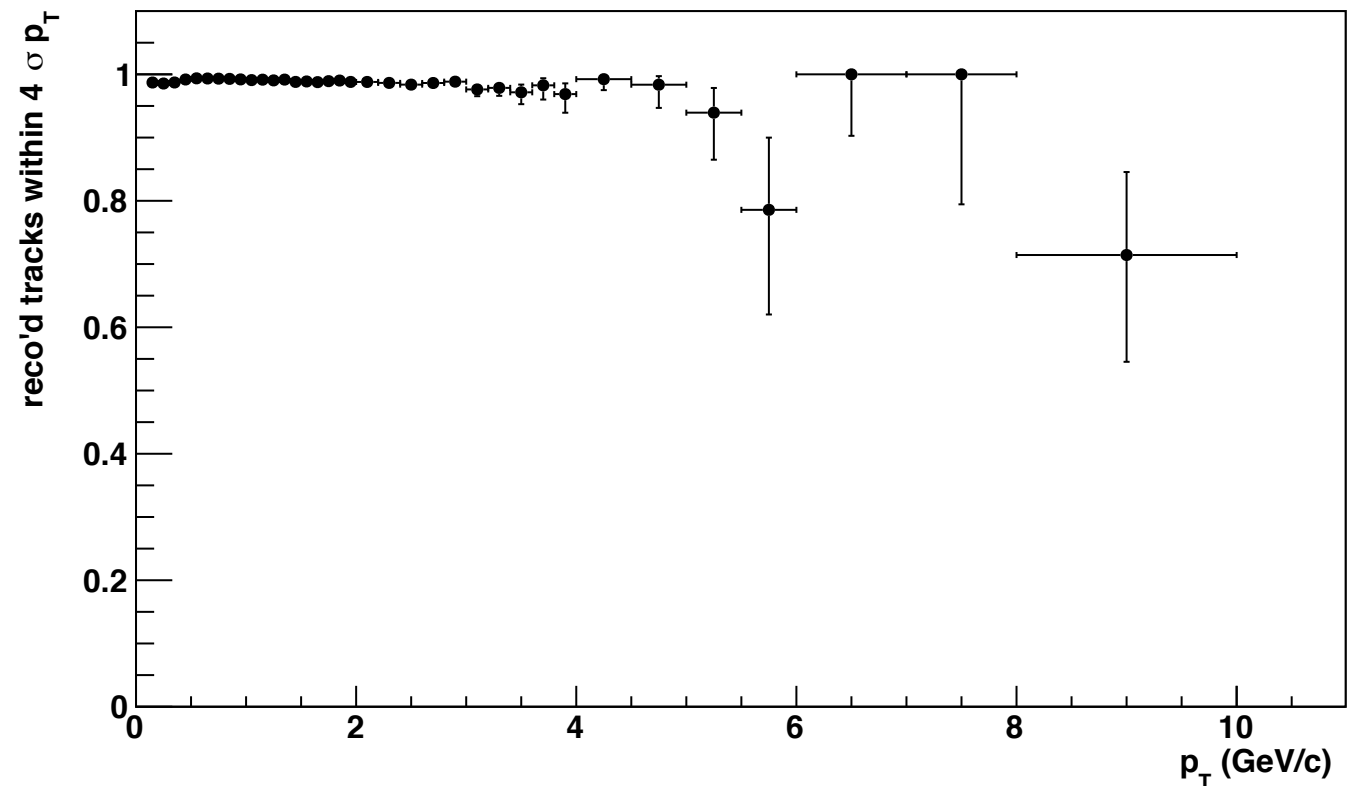
Record fraction of successful matches

Purity comparison (Hijing tracks only)

MAPS(3) + INTT(4) + TPC(60)

Fake tracks at high p_T are low p_T tracks reconstructed with incorrect momentum

Start to see evidence of a low rate of fake tracks at higher p_T



Algorithm:

Loop over **reconstructed** tracks

- Check reconstructed track p_T is within 4σ of truth

Record fraction of successes

Upsilon performance

$$Y(1S,2S,3S) \rightarrow e^+e^-$$

Mass resolution at Upsilon mass is
80 MeV

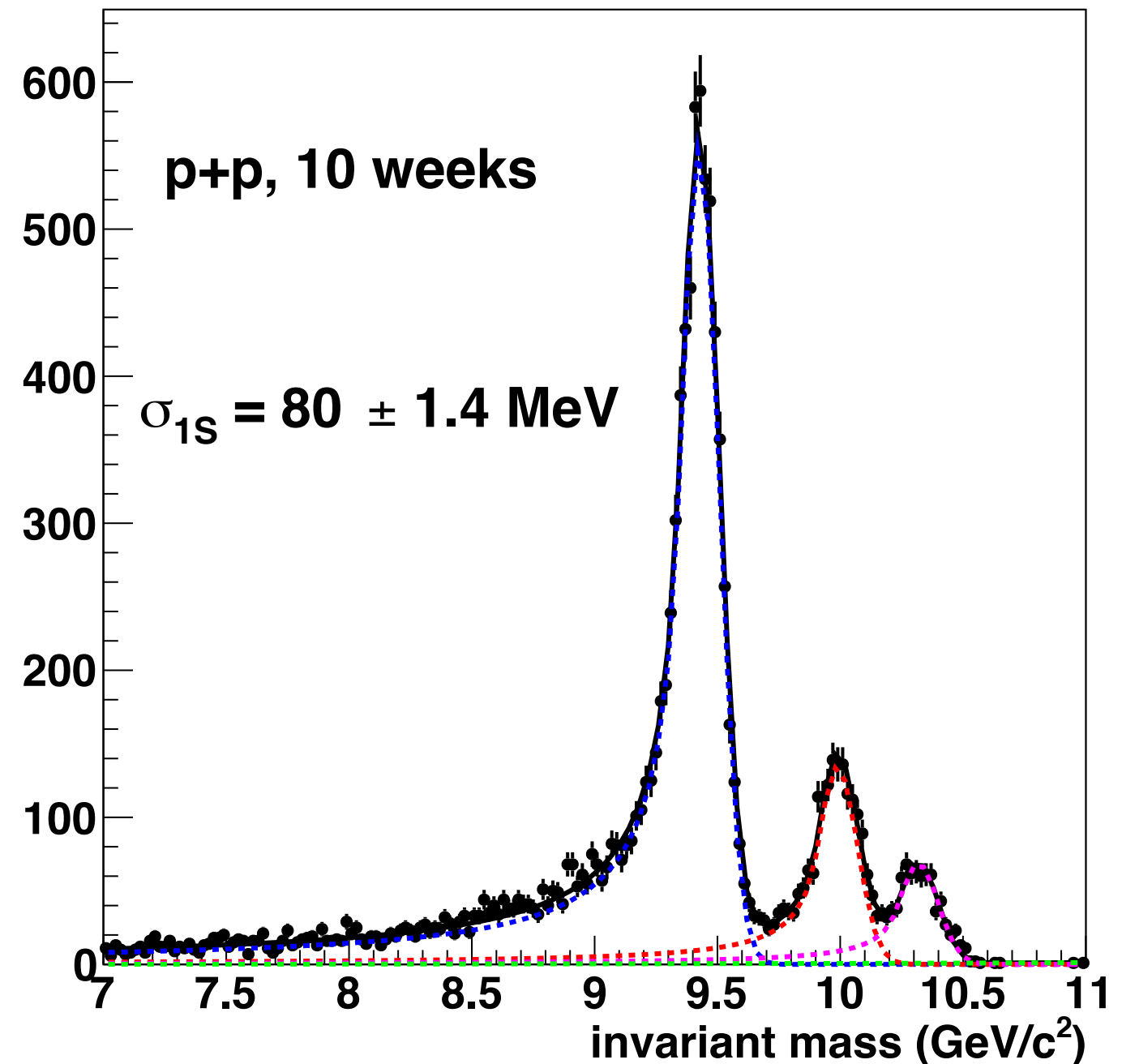
Easily exceeds our specification for
mass resolution of 100 MeV

Yields for 10 weeks p+p:

Y(1S) 8800

Y(2S) 2200

Y(3S) 1160

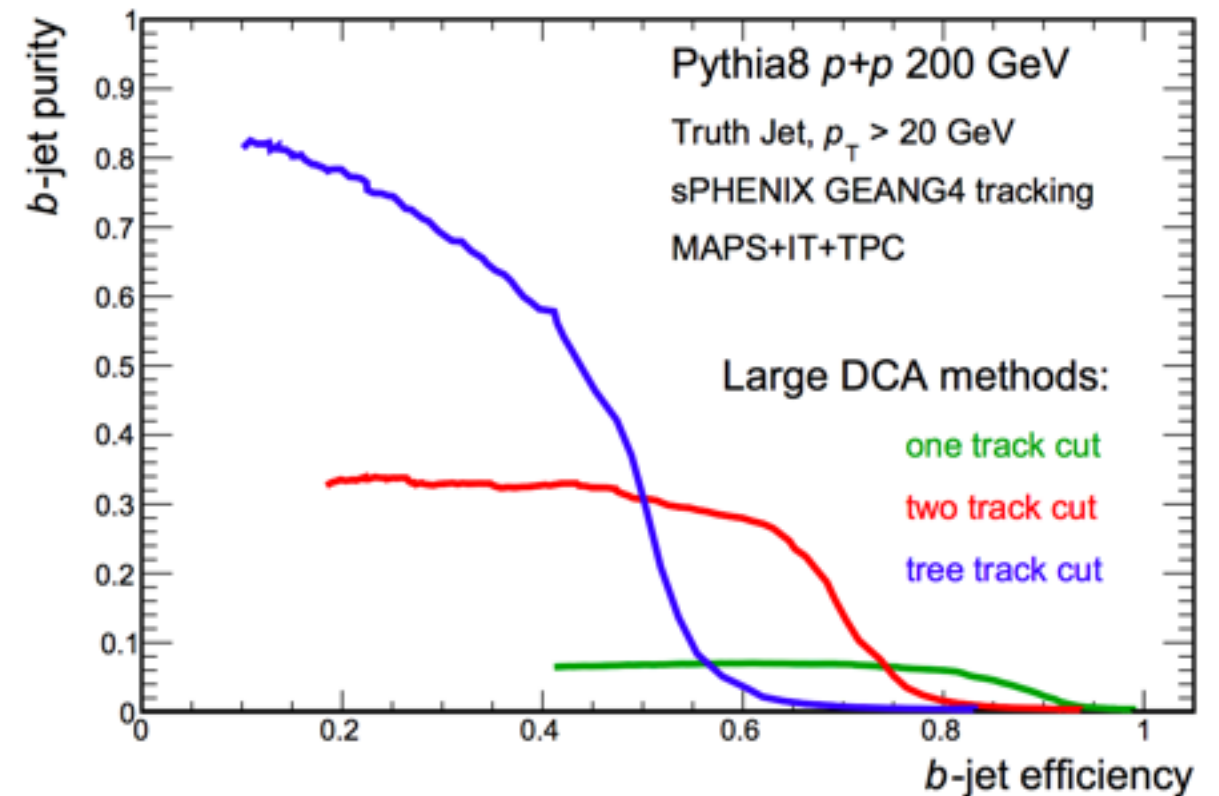
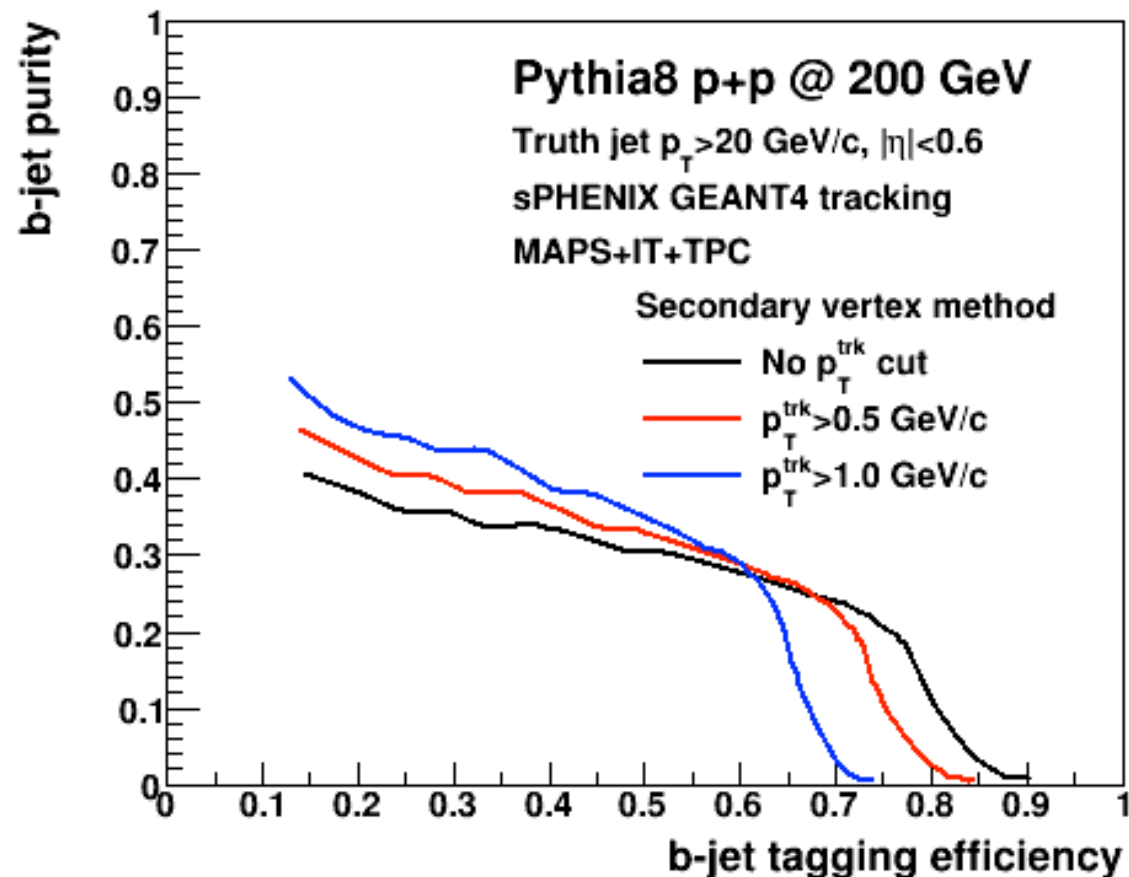


MAPS(3)+INTT(4)+TPC(60)

B-jet tagging performance

Plot of b-jet purity vs efficiency for **large DCA track counting** method

- 30% efficiency at 70% b-jet purity



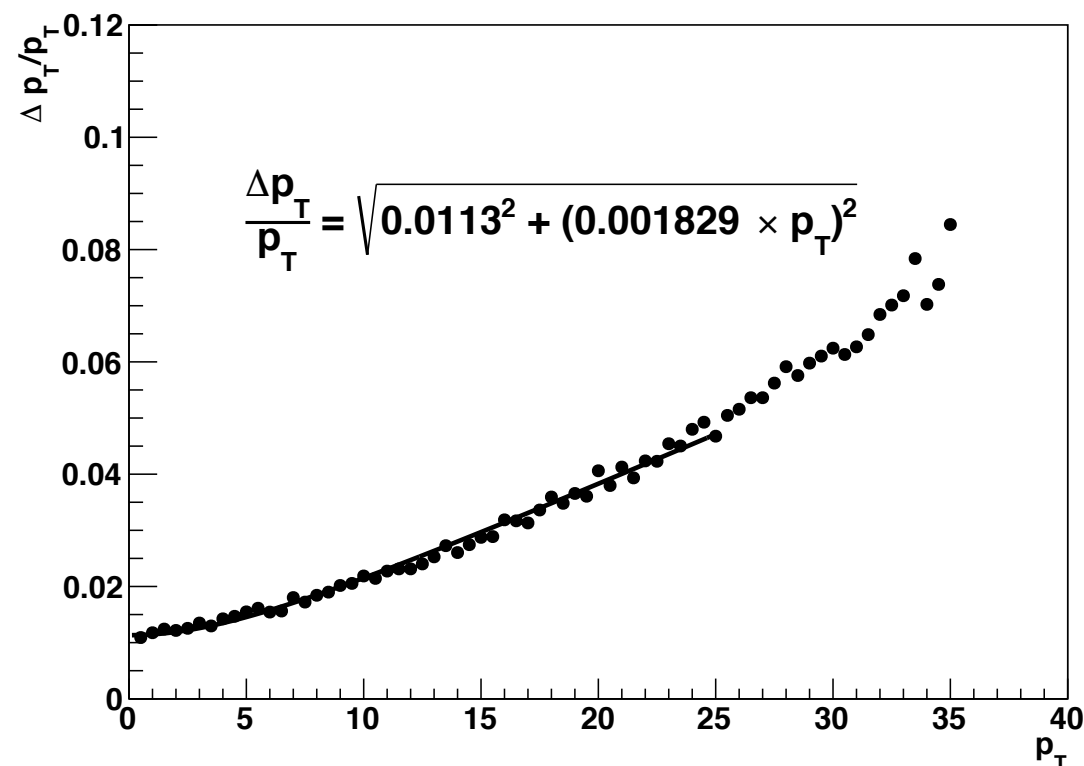
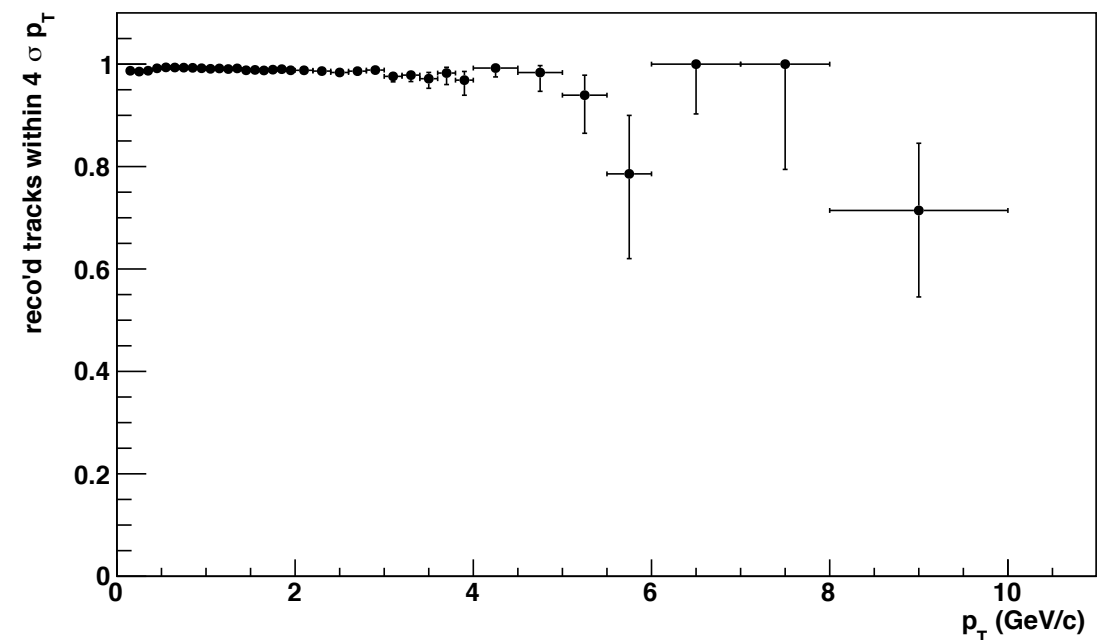
Secondary vertex finding method - uses RAVE (Reconstruction in an Abstract Versatile Environment) to find secondary vertices

- Comparable performance to 2-track cut of large DCA method

Jet substructure performance

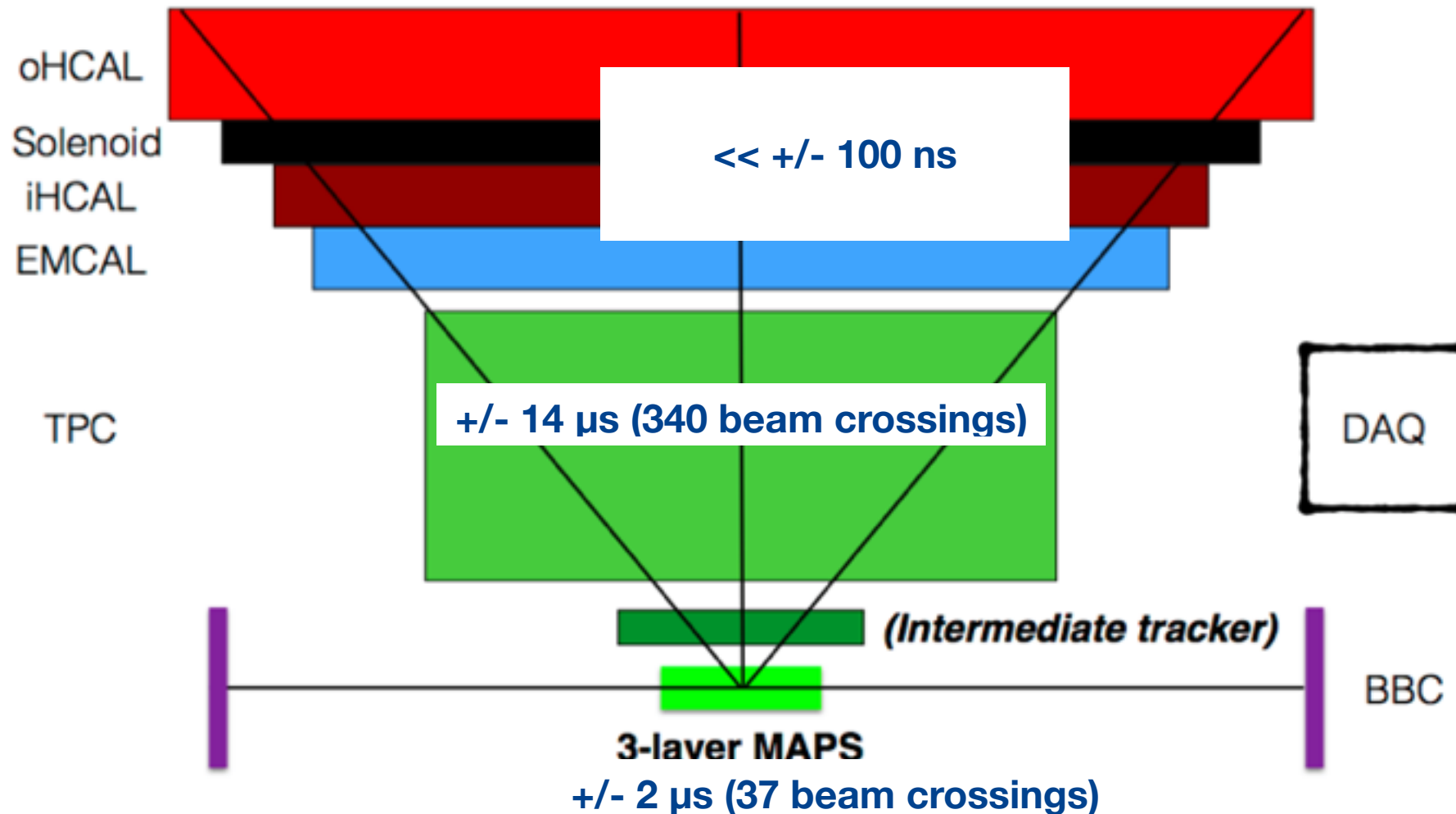
The ability to study jet substructure depends on

- Good pattern recognition at high multiplicity
- Acceptable momentum resolution at very high momentum



We are still working on optimizing the tracker performance in high multiplicity events

Event pileup



TPC has $\sim 6 \text{ cm} / \mu\text{s}$ drift velocity, integrates many beam crossings

Intermediate tracker resolves 1 beam crossing

Reject out of time track stubs in TPC and MAPS by

- Track χ^2
- Intermediate tracker confirmation

Simulations code has been modified to include out of time events

Initial results **w/o** intermediate tracker positive, studies are ongoing

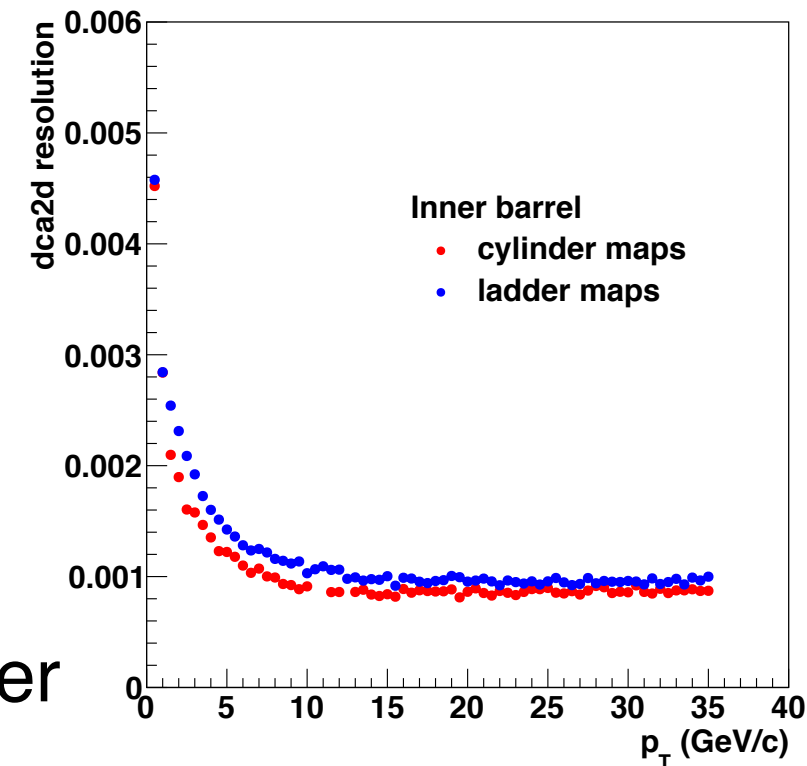
Future plans

MAPS cylinder cell model → MAPS ladders

ALICE ITS upgrade staves (inner, middle, outer) imported into sPHENIX

All associated coding completed, runs with existing tracker

- Takes only 1 hit per layer
- Differing material for each track not accounted for
- But not so bad anyway!



Future:

- More flexible tracking to handle multiple hits per layer
 - GenFit being tested
- Make material map available to tracker
- Multi-vertexing (RAVE) - implemented, being tested
- Ladder model for intermediate tracker
 - implemented for an earlier version, needs ladder geometry updated

Summary

We have performed simulations to evaluate the performance of a:

- 3 layer MAPS inner barrel
- 4 layer intermediate silicon strip tracker
- TPC outer tracker (active radius 30-78 cm)

We obtain:

- 80 MeV mass resolution for the Upsilon
- DCA resolution of $< 27 \mu\text{m}$ for $p_T > 1.0 \text{ GeV}/c$ tracks
- Excellent pattern recognition in central Au+Au Hijing events
- Good momentum resolution at high p_T for jet substructure studies
- Single track efficiency of $\sim 90\%$

The tracker performance leads to:

- Excellent mass resolution and efficiency for Upsilon measurements
- Excellent efficiency vs purity for b-tagged jets
- Low fake rate at high occupancy for jet substructure measurements

Backup